SAE J2343

Recommended Practices for LNG Powered Heavy Duty Trucks

Foreword - This SAE Recommended Practice is intended as a guide toward standard practice and is subject to change to keep pace with experience and technical advances. Its purpose is to promote safety and efficiency by making available to sellers and buyers of commercial LNG powered heavy duty trucks a recommended practice for construction, operation and maintenance of such trucks.

This Recommended Practice was developed by the Manufacturer's LNG Technical Subcommittee of the ATA Foundation's Alternative Fuels Task Force, which was organized in 1994 to guide the trucking and cryogenic industries in their efforts associated with the use of LNG as an Alternate Fuel for use in heavy duty trucks. Prior to the first Subcommittee meeting some preliminary work had been performed by the LNG onboard Fuel System Integration Committee (LOFSIC).

The first step in the Subcommittee's work was to perform a Failure Modes and Effects Analysis (FMEA), facilitated by Failure Analysis Associates. This study identified Failure Scenarios and the Failure Mechanisms which could potentially lead to the identified Failure Scenarios. It is the intent of these Recommended Practices to avoid the failure mechanisms identified by that study where possible, and to devise and recommend means of construction, operation and maintenance which would warn of an impending fault or failure, and/or mitigate the outcome should a failure occur.

Concurrent with the FMEA, the Subcommittee undertook an exhaustive review of existing codes, standards, recommended practices and regulations pertinent to trucks and LNG in force or in preparation, so that the Recommended Practice would be consonant with such, whether in force or under preparation. These are listed in Section 2.1.

This publication necessarily deals to some extent in generalities, since it is not possible to anticipate and address every individual set of conditions that might be found in constructing, operating and maintaining LNG powered heavy duty trucks. It is intended to be a practical guide illustrating rather than dictating the application of recommended practices. The correct application of these practices in any actual field situation must rely on sound judgment and experience. Whether to institute this voluntary Recommended Practice is up to each individual company, and members of the Subcommittee have not reached any agreement to use it or to **require** its use.

TABLE OF CONTENTS

1 Scope - This SAE Recommended Practice provides guidance for the construction, operation and maintenance of LNG powered heavy duty trucks.

1.2 Purpose - The purpose of this SAE Recommended Practice is to establish a uniform practice for construction, operation and maintenance of LNG powered trucks and is subject to change to keep pace with experience and technical advances. The revised Failure Modes and Effects Analysis which reflects the influence of this Recommended Practice is a separate document that is not part of this document but which is added as an informative appendix (Appendix 2).

2 References

2.1 Related Documents - The following publications were referred to in assembling this Recommended Practice.

2.1.1 NFPA Publication - Available from National Fire Protection Agency, 1 Batterymarch Park, P.O. Box 9101, Quincy MA 02269-9101.

NFPA 52 Standard for Compressed Natural Gas (CNG) Vehicular Fuel Systems

NFPA 57 Standard for Liquefied Natural Gas (LNG) Vehicular Fuel Systems

NFPA 70 National Electrical Code

2.1.2 Federal Highway Administration Publication - Available from Superintendent of Documents, U.S Government Printing Office, Washington D.C. 20402.

FHWA 393.65 - Fuel Tanks

FHWA 393.67 - Fuel Systems

2.1.3 ASME Publication - Available from American Society of Mechanical Engineers, United Engineering Center, 345 East 47th Street, New York, NY, 10017.

ASME Boiler and Pressure Vessel Code Section VIII Pressure Vessels, Division 1.

2.1.4 Compressed Gas Association Publication - Available from Compressed Gas Association Inc., 1725 Jefferson Davis Highway, Suite 1004, Arlington, VA, 22202-4102.

CGA Pressure Relief Standards S1.1 Part 1 - Cylinders for Compressed Gases.

CGA Pressure Relief Standards S1.2 Part 2 - Cargo and Portable Tanks for Compressed Gases.

CGA Pressure Relief Standards S1.3 Part 3 - Compressed Gases Storage Containers.

CGA Cleaning Equipment for O2 Service G4.1 - Tank Cleaning

2.1.5 Code of Federal Regulations Publication - Available from Superintendent of Documents, U.S Government Printing Office, Washington D.C. 20402.

CFR Title 49, Part 178, Standard 57 (DOT 4L) Welded Cylinders Insulated.

CFR Title 49, Part 571, Standard 301 Fuel System Integrity.

2.1.6 Texas Railroad Commission Publication - Available from Railroad Commission of Texas, Capitol Station P.O. Box 12967, Austin, Texas, 78711 - 2967.

Regulations for Liquefied Natural Gas

2.1.7 California Code of Regulations - Available from Barclays Law Publishers, Attn.: Client Services, P.O. Box 3066, South San Francisco, CA, 94083.

CCR Title 8 - Article 7.

CCR Title 13 - Section 935.

CCR Title 13 - Section 936.

2.1.8 ANSI/FCI Publication - Available from American National Standards Institute, 11 West 42nd Street, New York, NY, 10036-8002.

ANSI/FCI 70-2 Control Valve Seat Leakage.

2.1.9 FEMA Publication - Available from Federal Emergency Management Agency, Publications Office, 500 C Street S.W., Washington, DC, 20472.

Handbook of Chemical Hazard Analysis Procedures.

2.1.10 Liquid Carbonic Publication - Available from Liquid Carbonic Industries Corp., LNG Division, 810 Jorie Blvd., Oak Brook, IL, 60521-2216.

Storage and Safe Handling - Liquefied Natural Gas (LNG).

2.1.11 CCPS Publication - Available from the Center for Chemical Process Safety of the American Institute of Chemical Engineers, 345 East 47th St., New York, NY, 10017

Guidelines for Evaluating the Characteristics of Vapor Cloud Explosions, Flash Fires and BLEVEs

2.1.12 SAE Publications - Available from Technical Divisions, SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001

J703 - Fuel Systems - Trucks and Truck Tractors

2.2 Definitions - The following definitions were derived in assembling this Recommended Practice.

2.2.1 Family of Tanks - a group of tanks related by the following common characteristics or properties; same manufacturer, same insulation system and materials, same inner support system, mounted in the same manner, with piping components in the same or similar orientation, constructed with the same material types of the same strength and a volume not greater than 100 % of the test tank provided that the inner and outer vessels are of the same thickness as the test tank.

2.2.2 LOX - liquefied oxygen.

2.2.3 LNG - liquefied natural gas.

2.2.4 Maximum allowable working pressure (M.A.W.P.). - the highest pressure which can occur within a system prior to operation of the protecting relief valve.

2.2.5 Pressure Regulator - any device used to reduce pressure (independent of flow) exclusive of engine control regulators.

2.2.6 Ullage - the amount that a container lacks of being full.

2.2.7 Ullage Space - the volume of a container which is not full of liquid.

3 Construction

3.1 General - All materials used in valves, components and devices which could be exposed to LNG or cold LNG vapors during routine service (through vaporizer) should be rated for a service temperature of -166° C (-260° F) to +71° C (+160° F). All components within the engine compartment shall be rated for a service temperature of -40° C (-40° F) to +121° C (+250° F). All other components service should be rated for a service temperature of -40° C (-40° F) to +71° C (+160° F).

3.1.1 Fuel System Cleanliness after Reassembly - After assembly of the fuel system, the components between the tank and the engine should be free of dusts and debris before the system is put into service.

3.2 LNG Fuel Tank - The inner and outer shells of fuel tanks should be constructed of austenitic stainless steel, or equivalent. Tanks should be vacuum insulated with super insulation. Insulation system design life should be a minimum of the expected tank life as designed by the manufacturer. Insulation system should be designed such that product loss at static pressure should be less than 1% per day by volume. Tanks should have minimum hold time (build pressure without relieving) of 5 days when 75% full and saturated at 1/2 M.A.W.P. Tanks should be factory cleaned per CGA 4.1 (1996), and in lieu of customer specification shall follow the numerical and written criteria of CGA 4.1. The tank should retain an appropriate ullage space according to manufacturer's guidance during refueling such that the vessel can not become overfilled. The outer shell should be provided with an overpressure safety device to vent the annular insulation space if pressure becomes excessive.

3.2.1 Design - Each tank should be designed, fabricated and tested in accordance with DOT 4L or ASME Boiler Pressure Vessel Code.

3.2.2 Pressure Relief Valves - Containers should be equipped with pressure relief devices or pressure control valves required by the code under which the containers were designed and fabricated. Rupture discs should not be used. Each relief valve should be labeled with the manufacturer’s name, part number and set pressure. Each relief valve should have separate inlet connections which communicate directly with the vapor space of the tank. Each relief device should have a separate outlet. The primary pressure relief valve should be piped to a vent stack which extends above the cab of the truck. The vent stack should be suitable for LNG service. Primary and secondary relief valve outlets should be protected from fouling by dirt, debris, snow, ice and/or water. The vent stack should be sized to prevent flow restriction due to pressure drop. Gas exiting the vent stack or secondary relief valve should not impinge on enclosed areas, other vehicles, engine intakes or engine exhausts. In the case of dual tanks the primary relief valve outlet piping for each tank may be manifolded to a common outlet stack.

3.2.3 Level Gauging - Each tank system should have the ability to be provided with liquid level gauging which can be read from the cab. Accuracy shall be at least ± 1/8 capacity.

3.2.4 Pressure Gauging - Each tank system should be provided with a pressure gauge which can be read locally. Range should be at least 1.2 times the M.A.W.P. (maximum allowable working pressure). Gauge opening should be no larger than 0.055 in. and should connect above the maximum liquid level.

3.2.5 Fueling Connections - Each tank should be provided with a fueling connection with a dust cap to preclude the introduction of dirt to system. A secondary check valve independent of the fueling connector should be fitted between the fueling connector and the fuel tank. The fueling connector should be rated for the M.A.W.P. (maximum allowable working pressure) of the fuel tank. The fueling connector should be installed in accordance with the manufacturer's recommendations. The fueling connector should withstand the breakaway forces generated by the fueling station breakaway device. Recessed or flush mounted refueling connections should be provided with a spill path which directs liquid back outside the vehicle body. Fueling connections should be labeled "LNG only".

3.2.6 Manual Vent Valve - Each tank should be provided with a manual vent valve which can be used for controlled release of vapor from the tank ullage space. The vent valve should be connected to the vent stack, a vapor recovery connector or other safe location. The valve should be labeled "Manual Vent Valve" and shall indicate the closed direction. Closing the manual vent valve should not disable the pressure relief valves.

3.2.7 Shutoff Valves - Shutoff valves should be provided for each line which supplies fuel to the engine. These valves should be located at the fuel tank and be appropriately labeled ("Liquid Shutoff Valve" for liquid supplies and "Vapor Shutoff Valve" for vapor supplies). If manual, closed direction should also be labeled.

3.2.8 Excess Flow Valves - Excess flow devices should be provided for each line which supplies fuel to the engine. Excess flow devices should trip on a fuel line failure. Excess flow devices should be oriented so as to minimize the effect of road vibration on the valve actuation.

3.2.9 Connection Enclosure - All non-electrical connections and manifolds for the fuel tank should be protected from mechanical damage by means of a suitable connection enclosure. Enclosure should not be air tight or should be adequately vented such that pressure can not build up within the compartment. Each non-electrical component within the connection enclosure should be adequately labeled as to its function.

3.2.10 Tank Supports - Tank internal supports should be designed to "fail safe" and be tested in accordance with industry requirements. Testing should be consonant with and inconformance with applicable federal, state and local requirements. Fuel tanks shall be oriented and mounted in accordance with the OEM chassis manufacturer's recommendations. Tanks mounted within 8 inches of exhaust or other heat sources shall be shielded from radiant heating. The fuel tank shall not be supported by piping and/or piping connections. The fuel tanks shall be mounted such that no portion of the fuel tank projects forward of the front axle or behind the rear axle.

3.2.11 Labeling - Each tank should be labeled with the following minimum data; Design Code, Service Pressure, Serial Number, Capacity in Water Gallons, Manufacturer's Name or Trademark, Certification Date (Tested/Inspected), and LNG Symbol (Blue and White Diamond). All tank connections should be adequately labeled as to its function.

3.2.12 Drop Tests - Each family of fuel tanks should be drop tested to verify tank integrity. Drop tests should include a 30 foot drop test of the fuel tank on the most critical area of the tank (other than the piping end) and a 10 foot drop test on the piping end. Tank should contain an equivalent full weight of liquid nitrogen saturated at one half the maximum allowable working pressure (M.A.W.P.). There should be no loss of product for a period of one hour subsequent to the drop test other than relief valve operation and vapor between the filler neck and the secondary check valve in the case of a drop test involving the filler neck. Loss of vacuum, denting of the vessel, piping and piping protection and damage to the support structure system are acceptable. Drop test procedures are separate documents that are not part of this document but which have been added as an informative appendix (Appendix 1).

3.2.13 Flame Test - Each family of fuel tanks should be flame tested to verify tank integrity. Tank should contain an equivalent full level of liquid nitrogen saturated at one half the maximum allowable working pressure (M.A.W.P.). Tank should be inverted and subject to an external temperature of 538° C (1000° F).for 20 minutes without reaching relief pressure.

3.3 Vaporizer - The vaporizer should have the capacity to vaporize LNG completely at maximum engine fuel flow rates with minimum coolant design temperature. The fuel side of the vaporizer should be rated at the maximum allowable working pressure (M.A.W.P.). Provision should be made for bleeding air from the coolant side of the vaporizer. The vaporizer should be mounted as close to the fuel tank manifold as possible. The vaporizer should be protected from damage by road debris and from other mechanical damage by reasonable means. The vaporizer should be labeled for the intended service.

3.4 Pressure Regulators - If so equipped, pressure regulators should be rated at the M.A.W.P. (maximum allowable working pressure) of the regulator inlet line. Pressure regulators should be protected from damage by road debris and from other mechanical damage by reasonable means. The low pressure side of pressure regulators used to reduce the maximum allowable working pressure (M.A.W.P.) should be fitted with a relief device. This relief device should be rated for 1.2 times the rated flow of the regulator when supplied with the upstream M.A.W.P. (maximum allowable working pressure). The relief valve outlet should be suitably piped above the truck cab per the requirements of the primary fuel tank relief valve (see Section 3.2.2).

3.5 Automatic Shutoff Valves - Automatic shutoff valves should be rated at the M.A.W.P. (maximum allowable working pressure) of the supply (fuel tank or pressure regulator). Automatic shutoff valves should fail closed on loss of power regardless of orientation (i.e. mounted at any angle) or available pressure differential. The automatic shutoff valve should close on loss of ignition or loss of engine operation. Automatic shutoff valves should be protected from damage by road debris and from other mechanical damage by reasonable means.

3.6 Failure/Warning Devices - A warning should activate in the cab if abnormally low temperature is detected downstream of the vaporizer.

3.7 Fittings & Piping/Tubing - Piping should be shielded from radiant heating which exceeds its temperature limitations. The number of fittings should be kept to a minimum. Threaded pipe connections should be kept to a minimum. Fittings should be suitable for the intended service and shall be included in the vibration/durability and corrosion testing. All piping and tubing should be protected from damage by road debris by reasonable means and from other mechanical damage. LNG piping should be provided with insulation or shielding for personnel protection. All piping and tubing should be adequately supported. Pipe sealant should be suitable for the intended service. Vent stack connections should allow sufficient flexibility to accommodate differential movement. The completed fuel system should be leak tested with a suitable medium at operating pressure prior to the introduction of product to the fuel system. All cryogenic piping should be protected against blocking LNG between valved sections by hydrostatic relief or other suitable means.

3.8 Corrosion/Vibration/Durability Integrity - The systems and subsystems unique to LNG operations should be corrosion, vibration and durability demonstrated as part of the overall vehicle testing process by the chassis OEM to verify overall integrity.

3.9 Gas Detection - A gas detection system installed per the device manufacturer's recommendations should warn of the presence of methane in the following locations;

1. Within the truck cab.
2. Within the engine compartment.

Detection should cover periods when the engine is and is not operating.

3.10 Electrical - Electrical devices mounted within the connection enclosure should be suitable for Class I Division 2 hazardous area (NFPA 70 National Electrical Code) or equal. Electrical devices which connect to the fuel system shall be of the double seal type per NFPA 70, or equal. All branch circuits should be protected from overcurrent by suitable means.

3.11 Gas Filtration - A gas filter(s) which can be isolated from the fuel supply should be included in the vehicle fuel system. The filter(s) should be shielded from excessive radiant heat and road debris by reasonable means. The filter(s) should be rated at the maximum allowable working pressure (MAWP) of the supply (fuel tank or pressure regulator).

4 Operation

4.1 General - Due to the large degree of variation possible in system configuration and component specifics, this section will outline the content which should be covered by the manufacturer/suppliers' (i.e.chassis OEM, engine manufacturer, tank supplier, etc.) Operating Manual. It is the intent that the content described be presented in sufficient depth and clarity so as to provide basic understanding of systems unique to LNG powered heavy duty trucks. Manufacturer/supplier will provide operations and maintenance manuals for their specific components. The vehicle builder has the overall responsibility for collection and consolidation of all LNG related operation and maintenance manuals.

4.2 LNG Safety - The following topics should be covered in the operating manual when addressing LNG Safety;

4.2.1 Chemical and Physical Properties - The following properties of LNG should be treated in the operating manual for LNG powered heavy duty trucks; Compositional characteristics, i.e. Material Safety Data Sheets *(MSDS)*, general liquid properties, odor properties, cryogenic properties, general vapor properties and spill/leak characteristics.

4.2.2 Safety Hazards - The following safety hazards should be explained in the operating manual; cold metal contact hazards, cryogenic burn hazards, asphyxiation hazards, overpressurization hazards and fire hazards associated with the use of LNG as a vehicle fuel. Liquid spills and vapor releases into the atmosphere should be discussed. Effects of liquid spills and vapor containment should be discussed; e.g., LNG flowing down storm sewer or equipment garage vapor containment.

4.2.3 Protective Equipment - The use of appropriate protective equipment during fueling should be discussed in the operating manual.

4.2.4 First Aid & Emergency Services - The First Aid issues to be discussed in the operating manual should include cryogenic burn first aid; reminders to alert operators reporting incidents to alert response personnel that LNG fuel is involved should be included.

4.3 Fuel System Overview - The following fuel system topics should be covered in the operating manual;

4.3.1 Fuel Tank System - The basic construction, operation and safety features (i.e. relief valves, manual shutoff valves, excess flow valves, etc.) shall be discussed in sufficient detail as to provide basic understanding of systems unique to LNG powered heavy duty trucks.

4.3.2 Vaporizer - The basic construction, operation and safety features (i.e. low temperature warning system, etc.) should be discussed in sufficient detail to provide basic understanding of vaporizer system operation.

4.3.3 Pressure Relief Valves - The basic construction, operation and aspects should be discussed in sufficient detail to provide basic understanding of relief valve operations.

4.3.4 Automatic and Manual Shutoff Valves - The basic construction, operation and aspects should be discussed in sufficient detail to provide basic understanding of shutoff valve operation.

4.3.5 Vent Stack - The basic construction, operation and characteristics should be discussed in sufficient detail to provide basic understanding of vent stack operations. Manual venting should be clearly explained.

4.4 Operational Safety - At a minimum the following topics should be covered in the operating manual when addressing Operational Safety;

4.4.1 Pre & Post Operational Safety - For pre & post operational safety the operating manual should explain how to detect obvious leaks (vapor cloud or hissing from fuel line) and what to do about them.

4.4.2 Low Temperature Warning - The function and remedial action necessary for the low temperature warning system should be adequately explained in the operating manual.

4.4.3 Methane Detection - The function and remedial action necessary for the methane detection system should be adequately explained in the operating manual.

4.5 Fueling Safety - The following topics should be covered in the operating manual when addressing LNG Safety;

4.5.1 Fueling Procedure - The fueling procedure should be included in the operating manual and should cover the following topics; shutting off the vehicle, grounding the vehicle, ensuring that the vehicle is not moved with the fuel hose connected to the vehicle, fuel connector operation, fuel connector spillage, cold metal contact and required personnel protection.

4.5.2 Grounding - The elimination of electrostatic discharge during fuel hose connection by adequately grounding the vehicle during fueling shall be covered in the operating manual.

4.5.3 Dust Caps - The importance of the use of dust caps in eliminating moisture and dirt contamination should be covered in the operating manual.

4.5.4 Tank Fueling with Venting Required - A fueling procedure when tank pressure relief is necessary should be included in the operating manual, and should address the hazards involved when venting vapor from the fuel tanks. Initial fueling or refueling of a tank which has been emptied involves a special procedure which should be addressed.

4.5.4.1 Tank Venting - Circumstances when manual venting of the tank is required, and procedures for carrying out such venting should be included, and should address the hazards involved when venting vapor from the fuel tank. Initial tank fueling or refueling of a tank which has been emptied involves special procedures which should be addressed, including the fact that manual venting will cause fuel weathering.

4.6 Fuel Quality - This topic should be covered in the operating manual when addressing Fuel Quality and should also be specific to the engine manufacturers' requirements for the year and type of engine.

4.6.1 Fuel Specification - The minimum methane concentration and maximum inert, heavy hydrocarbon and contaminant concentrations for the fuel delivered to the engine should be specified in the operating manual. An adequate description of LNG weathering and nitrogen concentration should be contained in the operating manual.

4.6.2 Fuel Contamination - The operating manual should contain a discussion of contamination risks.

4.6.3 Use of CNG - The operating manual should explain the use of properly regulated compressed natural gas (CNG) to move the vehicle when necessitated by circumstances.

4.6.4 Weathering of LNG Fuel - Fuel venting caused by either long term parking of LNG vehicles or manual venting can lead to weathering of LNG fuel. Fuel composition may be altered and may violate engine manufacturer's specifications resulting in driveability problems or possible engine damage.

4.7 Indoor Parking Safety - The following topics must be covered in the operating manual when addressing indoor parking safety:

4.7.1 Short Term Parking - The following topics should be covered in the operating manual concerning short term parking; suggested duration, preference to outdoor parking due to potential for leaks, relief valve leakage or operation, the potential need in local codes for structure methane detection with indoor parking, and the necessity for piping of the relief stack outside the building structure.

4.7.2 Long Term Parking - The Operating Manual should define the duration of long term parking, and the special considerations with regard to the LNG fuel system and defueling to prevent potential hazards associated with long term parking should be addressed.

5 Maintenance

5.1 General - Due to the large degree of variation possible in system configuration and component specifics, this section will outline the content which should be covered by the manufacturer/supplier's Maintenance Manual. The document should provide technicians sufficient understanding to work on LNG powered trucks safely, and contain a CAUTION against substitution of components or materials other than those supplied or recommended by the manufacturers.

5.2 LNG Safety - The following topics should be covered in the maintenance manual when addressing LNG Safety;

5.2.1 Chemical and Physical Properties - The following properties of LNG should be treated in the maintenance manual for LNG powered heavy duty trucks; Compositional characteristics MSDS, general liquid properties, odor properties, cryogenic properties, general vapor properties and spill/leak characteristics.

5.2.2 Safety Hazards - The following safety hazards should be explained in the maintenance manual; cold metal contact hazards, cryogenic burn hazards, asphyxiation hazards, overpressurization hazards and fire hazards associated with the use of LNG as a vehicle fuel. Liquid spills and vapor releases into the atmosphere should be discussed. Effects of liquid spills and vapor containment should be discussed; e.g. LNG flowing down sewer or equipment garage vapor containment.

5.2.3 Protective Equipment - The use of appropriate protective equipment during fueling, fuel system maintenance and defueling should be discussed in the maintenance manual.

5.3 Facility Safety - The following topics should be covered in the maintenance manual when addressing maintenance facility safety along with a discussion of risks associated with each;

5.3.1 Fuel Supply Isolation - The maintenance manual should explain the necessity for isolation of the fuel system by closing the manual shutoff valves at the fuel tank any time that an LNG powered vehicle is brought into the maintenance facility for any reason.

5.3.2 Relief/Vent Stack Piping - The maintenance manual should explain the necessity for piping the relief/vent stack to a safe outdoor location any time that an LNG powered vehicle is brought into the maintenance facility for any reason.

5.3.3 Methane Detection - The maintenance manual should explain the necessity for methane detection for checking for fuel leakage any time that an LNG powered vehicle is brought into the maintenance facility for any reason.

5.3.4 Fuel System Cleanliness after Reassembly - The maintenance manual should explain the need to assure that the fuel system between the tank and engine be free of all dust and debris before being returned to service after reassembly.

5.3.5 Fuel Tank Maintenance - The maintenance manual should explain the procedure for defueling the fuel tank prior to removing or performing maintenance on it. Disposal of removed fuel should be in conformance with local regulations.

5.3.6 Fuel System Leaks - The maintenance manual should explain the necessity for repairing fuel system leaks prior to bringing an LNG powered vehicle into the maintenance facility.

5.3.7 Firefighting Techniques - Because of differences in firefighting characteristics of LNG compared to conventional fuels, the maintenance manual should address basic reference materials and officials to be consulted for further guidance.

5.4 Pressure Relief Valve Maintenance - The maintenance manual should discuss the appropriate service interval for relief valves and other components unique to the LNG fuel system.

5.5 Fuel System Modification and Maintenance - The maintenance manual should contain a CAUTION against modifying the LNG Fuel System from its original (OEM) configuration. The following topics should be covered in the maintenance manual when addressing fuel system maintenance;

5.5.1 Fuel System Overview - The basic construction, operation, maintenance and safety features (i.e. relief valves, manual shutoff valves, excess flow valves, etc.) should be discussed in sufficient detail to familiarize the service technician with the LNG fuel system.

5.5.1.1 Fuel System Bleed Down - Appropriate CAUTIONS regarding pressurized fuel lines and components and appropriate methods for de-pressurizing fuel lines and components for maintenance work should be included.

5.5.2 Fuel Tank - The basic construction, operation, maintenance and safety features (i.e. relief valves, manual shutoff valves, excess flow valves, etc.) should be discussed in sufficient detail to familiarize the service technician with proper maintenance procedures for servicing the fuel tank and its related components.

5.5.2.1 Tank Venting - Circumstances when manual venting of the tank is required, and procedures for carrying out such venting should be included, and should address the hazards involved when venting vapor from the fuel tank. Initial tank fueling or refueling of a tank which has been emptied involves special procedures which should be addressed, including the fact that manual venting will cause fuel weathering.

5.5.3 Vaporizer - The basic construction, operation, maintenance and safety features (i.e. low temperature warning system, etc.) should be discussed in sufficient detail to familiarize the service technician with proper maintenance procedures for servicing the vaporizer and its related components.

5.5.4 Pressure Relief Valves - The basic construction, operation, maintenance and aspects should be discussed in sufficient detail to familiarize the service technician with proper maintenance procedures for servicing the pressure relief valves and their related components.

5.5.5 Shutoff Valves - The basic construction, operation, maintenance and aspects should be discussed in sufficient detail to familiarize the service technician with proper maintenance procedures for servicing the shutoff valves and their related components.

5.5.6 Leak Testing - The maintenance manual should explain the procedure for leak testing the fuel system if any maintenance is done on the fuel system.

5.5.7 Protection from Ignition Sources - The maintenance manual should explain the proper procedure for protecting the fuel system from ignition sources such as welding, flame cutting, etc. which may be performed on the vehicle. The potential hazards which could arise from weld spatter, arc strikes, cutting a live fuel line, etc. should be clearly explained.

5.5.8 Other System Components - The maintenance manual should discuss all fuel system replacement parts giving replacement part specifications, appropriate installation and servicing procedures and other unique elements relating to the LNG fuel system.

APPENDIX 1

DROP TEST PROCEDURES

TEST PROCEDURE FOR LNG VEHICLE FUEL TANKS
30 FOOT CRITICAL AREA DROP

1.0 PURPOSE

This procedure defines the sequence of events to be followed in execution of the 30 foot critical area drop test of LNG vehicle fuel tanks. This procedure describes the orientation, execution, documentation and pass/fail criteria for the test.

2.0 SCOPE

The drop test will subject a full size vehicle fuel tank to a free fall impact onto an unyielding surface from a height of 30 feet. The fuel tank will be released by firing one or more explosive cable cutters simultaneously. The fuel tank will impact the outer shell on the critical area as determined by the manufacturer. The fuel tank will be filled with an equivalent full weight of liquid nitrogen saturated to at least 1/2 the maximum allowable working pressure of the fuel tank. There shall be no loss of product other than relief valve operation and loss of vapor between the filler neck and the secondary relief valve in the case of a test involving the filler neck. Loss of vacuum; denting of the vessel, piping and piping protection and damage to the support system are acceptable. The drop test will be documented using two standard speed video cameras and still photographs.

3.0 PRE-DROP PREPARATIONS

Prior to drop testing a vehicle fuel tank the manufacturer will provide an orientation which results in impact of the most critical area for the tank to be tested. Lifting lugs will then be attached using epoxy adhesive such that the fuel tank can be suspended from the lifting lugs at the orientation specified by the manufacturer. Once the lifting lugs have cured the vessel will be moved to the cryogenic test area where it will be filled liquid nitrogen to simulate a full load of LNG (liquefied natural gas). The liquid nitrogen will be saturated to at least 1/2 the maximum allowable working pressure of the fuel tank. The tank is then transported to the drop pad for drop testing.

4.0 DROP TEST

Once the fuel tank to be drop tested has been filled and has reached the drop pad it will be connected to the drop pad hoist and a preliminary check of vessel orientation and tank pressure will be performed. Adjustments as necessary will be made until orientation and pressure are satisfactory. Pressure will be checked via the remote pressure monitoring transducer which is connected via quick disconnect to the ullage space of the fuel tank. Pressure readout will be setup for monitoring from outside the drop pad fence. Once the vessel pressure has been recorded on the drop test data sheet the fuel tank vent manual shutoff valve will be closed and the transducer will be disconnected.

The vessel is then be weighed by means of a 2000 pound load cell in the main lifting line. Combined load cell and readout repeatability shall be better than 1%. Load cell readout will be setup for remote monitoring from outside the drop pad fence. Weight is recorded on the drop test data sheet.

Wind speed is then checked to ensure that wind is below 10 MPH with gusts under 15 MPH. Wind conditions and ambient temperature are recorded on the drop test data sheet.

The armor plate surface is measured using a hand held surface thermometer. The armor plate must be above 0°F in order to proceed. The armor plate temperature is recorded on the drop test data sheet.

The stadia boards are then moved into position and clamped in place. The boards will be positioned such that the reference grid matches at the inside corner of the boards.

The impact area will be cleared of all unauthorized personnel. The fuel tank is then lowered and the explosive cable cutter is installed and wired to the zip cord which will extend to the firing mechanism located outside the drop pad fence. The explosive circuit is then checked for continuity.

Tag lines and a 30 foot drop height indicator string are then attached to the fuel tank. The fuel tank is raised to the drop height, the height is verified, and the tension on the hoist hold down cables is checked. The tank orientation will be corrected with the tag lines and the height verification tag line will be removed.

The impact area will then be washed down with water or antifreeze based solution if the surface has frost on it. This will aid in visualizing the impact.

The blasting machine will be wired to the explosive cutter zip cord and a status check made by the test manager. The video cameras will then be started. Upon confirmation that video cameras are operational all personnel will be evacuated from the fenced drop pad area. The blasting machine will be charged. Shortly after the blasting machine has been charged (1-2 seconds) the explosive cutter will be fired.

5.0 POST-DROP MEASUREMENTS

After impact the fuel tank will be approached by two technicians who have had training in cryogenic safety. The technicians will use self contained breathing apparatus, cotton shirt and pants, loose fitting work gloves and work boots. No other personnel will be permitted within the drop pad area fence.

The final location of the fuel tank, orientation to the drop test pad and fuel tank position will be documented on video and with 35 mm photographs.

The fuel tank will then be reconnected to the drop pad hoist and weighed by means of the lifting line load cell. Weight is recorded on the drop test data sheet at this time and every ten minutes thereafter.

The remote fuel tank pressure monitor system will be reconnected at this point. The technicians will again evacuate the drop pad area.

Fuel tank pressure will be checked at this point and every ten minutes thereafter for one hour. Fuel tank pressure will be recorded on the drop test data sheet.

If the relief valve should operate during the one hour interval after the drop, tank pressure and weight will be recorded immediately upon relief valve reseat.

One hour after the fuel tank has been dropped and the final data has been recorded the fuel tank will again be approached by the two technicians who have had training in cryogenic safety. The technicians will once again use self contained breathing apparatus, cotton shirt and pants, loose fitting work gloves and work boots. No other personnel will be permitted within the drop pad area fence. The liquid nitrogen will be removed from the fuel tank and vented to the atmosphere in a safe manner. Venting will continue until all liquid has been removed and the tank has been completely depressurized. Once this has been completed other personnel may enter the drop pad area.

6.0 PASS/FAIL CRITERIA

There shall be no loss of product for a period of one hour after the drop other than relief valve operation and loss of vapor between the filler neck and the secondary relief valve in the case of a test involving the filler neck. Loss of vacuum; denting of the vessel, piping and piping protection and damage to the support system are acceptable.

7.0 DOCUMENTATION

A letter report will be prepared supported by the data sheets. Two copies of the test video tape will also be provided. Documentation of the test will be treated as confidential and will be submitted to the manufacturer only.

TEST DATA FOR LNG VEHICLE FUEL TANK
30 FOOT CRITICAL AREA DROP

PREDROP DATA

Initial Fuel Tank Pressure : ____________ psig.

Initial Fuel Tank Weight : ____________ lbs.

Wind Speed : ____________ mph.

Ambient Temperature : ____________ °F.

Armor Plate Temperature : ____________ °F.

POSTDROP DATA

Time Comments	Tank Pressure	Tank Weight
____	_______psig	_______lbs
____	_______psig	_______lbs
____	_______psig	_______lbs
____	_______psig	_______lbs
____	_______psig	_______lbs
____	_______psig	_______lbs
____	_______psig	_______lbs
____	_______psig	_______lbs
____	_______psig	_______lbs
____	_______psig	_______lbs
____	_______psig	_______lbs
____	_______psig	_______lbs

TEST PROCEDURE FOR LNG VEHICLE FUEL TANKS
10 FOOT PIPING AREA DROP

1.0 PURPOSE

This procedure defines the sequence of events to be followed in execution of the 10 foot piping area drop test of LNG vehicle fuel tanks. This procedure describes the orientation, execution, documentation and pass/fail criteria for the test.

2.0 SCOPE

The drop test will subject a full size vehicle fuel tank to a free fall impact onto an unyielding surface from a height of 10 feet. The fuel tank will be released by firing one or more explosive cable cutters simultaneously. The fuel tank will impact the outer shell on the critical area as determined by the manufacturer. The fuel tank will be filled with an equivalent full weight of liquid nitrogen saturated to at least 1/2 the maximum allowable working pressure of the fuel tank. There shall be no loss of product other than relief valve operation and loss of vapor between the filler neck and the secondary relief valve in the case of a test involving the filler neck. Loss of vacuum; denting of the vessel, piping and piping protection and damage to the support system are acceptable. The drop test will be documented using two standard speed video cameras and still photographs.

3.0 PRE-DROP PREPARATIONS

Prior to drop testing a vehicle fuel tank the an orientation will be selected which results in impact of the piping area for the tank to be tested. Lifting lugs will then be attached using epoxy adhesive such that the fuel tank can be suspended from the lifting lugs at the orientation selected. Once the lifting lugs have cured the vessel will be moved to the cryogenic test area where it will be filled liquid nitrogen to simulate a full load of LNG (liquefied natural gas). The liquid nitrogen will be saturated to at least 1/2 the maximum allowable working pressure of the fuel tank. The tank is then transported to the drop pad for drop testing.

4.0 DROP TEST

Once the fuel tank to be drop tested has been filled and has reached the drop pad it will be connected to the drop pad hoist and a preliminary check of vessel orientation and tank pressure will be performed. Adjustments as necessary will be made until orientation and pressure are satisfactory. Pressure will be checked via the remote pressure monitoring transducer which is connected via quick disconnect to the ullage space of the fuel tank. Pressure readout will be setup for monitoring from outside the drop pad fence. Once the vessel pressure has been recorded on the drop test data sheet the fuel tank vent manual shutoff valve will be closed and the transducer will be disconnected.

The vessel is then be weighed by means of a 2000 pound load cell in the main lifting line. Combined load cell and readout repeatability shall be better than 1%. Load cell readout will be setup for remote monitoring from outside the drop pad fence. Weight is recorded on the drop test data sheet.

Wind speed is then checked to ensure that wind is below 10 MPH with gusts under 15 MPH. Wind conditions and ambient temperature are recorded on the drop test data sheet.

The armor plate surface is measured using a hand held surface thermometer. The armor plate must be above 0°F in order to proceed. The armor plate temperature is recorded on the drop test data sheet.

The stadia boards are then moved into position and clamped in place. The boards will be positioned such that the reference grid matches at the inside corner of the boards.

The impact area will be cleared of all unauthorized personnel. The fuel tank is then lowered and the explosive cable cutter is installed and wired to the zip cord which will extend to the firing mechanism located outside the drop pad fence. The explosive circuit is then checked for continuity.

Tag lines and a 10 foot drop height indicator string are then attached to the fuel tank. The fuel tank is raised to the drop height, the height is verified, and the tension on the hoist hold down cables is checked. The tank orientation will be corrected with the tag lines and the height verification tag line will be removed.

The impact area will then be washed down with water or antifreeze based solution if the surface has frost on it. This will aid in visualizing the impact.

The blasting machine will be wired to the explosive cutter zip cord and a status check made by the test manager. The video cameras will then be started. Upon confirmation that video cameras are operational all personnel will be evacuated from the fenced drop pad area. The blasting machine will be charged. Shortly after the blasting machine has been charged (1-2 seconds) the explosive cutter will be fired.

5.0 POST-DROP MEASUREMENTS

After impact the fuel tank will be approached by two technicians who have had training in cryogenic safety. The technicians will use self contained breathing apparatus, cotton shirt and pants, loose fitting work gloves and work boots. No other personnel will be permitted within the drop pad area fence.

The final location of the fuel tank, orientation to the drop test pad and fuel tank position will be documented on video and with 35 mm photographs.

The fuel tank will then be reconnected to the drop pad hoist and weighed by means of the lifting line load cell. Weight is recorded on the drop test data sheet at this time and every ten minutes thereafter.

The remote fuel tank pressure monitor system will be reconnected at this point. The technicians will again evacuate the drop pad area.

Fuel tank pressure will be checked at this point and every ten minutes thereafter for one hour. Fuel tank pressure will be recorded on the drop test data sheet.

If the relief valve should operate during the one hour interval after the drop, tank pressure and weight will be recorded immediately upon relief valve reseat.

One hour after the fuel tank has been dropped and the final data has been recorded the fuel tank will again be approached by the two technicians who have had training in cryogenic safety. The technicians will once again use self contained breathing apparatus, cotton shirt and pants, loose fitting work gloves and work boots. No other personnel will be permitted within the drop pad area fence. The liquid nitrogen will be removed from the fuel tank and vented to the atmosphere in a safe manner. Venting will continue until all liquid has been removed and the tank has been completely depressurized. Once this has been completed other personnel may enter the drop pad area.

6.0 PASS/FAIL CRITERIA

There shall be no loss of product for a period of one hour after the drop other than relief valve operation and loss of vapor between the filler neck and the secondary relief valve in the case of a test involving the filler neck. Loss of vacuum; denting of the vessel, piping and piping protection and damage to the support system are acceptable.

7.0 DOCUMENTATION

A letter report will be prepared supported by the data sheets. Two copies of the test video tape will also be provided. Documentation of the test will be treated as confidential and will be submitted to the manufacturer only.

TEST DATA FOR LNG VEHICLE FUEL TANK
10 FOOT PIPING AREA DROP

PREDROP DATA

Initial Fuel Tank Pressure : ____________ psig.

Initial Fuel Tank Weight : ____________ lbs.

Wind Speed : ____________ mph.

Ambient Temperature : ____________ °F.

Armor Plate Temperature : ____________ °F.

POSTDROP DATA

Time	Tank Pressure	Tank Weight	Comments
____	_______psig	_______lbs	
____	_______psig	_______lbs	
____	_______psig	_______lbs	
____	_______psig	_______lbs	
____	_______psig	_______lbs	
____	_______psig	_______lbs	
____	_______psig	_______lbs	
____	_______psig	_______lbs	
____	_______psig	_______lbs	
____	_______psig	_______lbs	
____	_______psig	_______lbs	
____	_______psig	_______lbs	

Appendix 2

Failure Modes and Effects Analysis

Introduction - The Manufacturer's LNG Technical Subcommittee of the ATA Foundation Alternative Fuels Task Force was organized in 1994 to guide the trucking industry in their efforts associated with the use of LNG as an Alternate Fuel for use in heavy duty trucks. The first step in their investigation as a technical subcommittee was to perform a Failure Modes and Effects Analysis (FMEA) in cooperation with Failure Analysis Associates (FaAA). The FMEA was conducted at FaAA premises in Menlo Park, California on October 20 and 21,1994. This study identified Failure Scenarios and the Failure Mechanisms which could potentially lead to the identified Failure Scenarios. The goal of the technical subcommittee in drafting the SAE Recommended Practices for LNG Powered Heavy Duty Trucks was to avoid the failure mechanisms identified by that study where possible and to mitigate the outcome should a failure occur. To this end the original FMEA was revised to add three additional columns to cover; the Recommended Practice Impact, the revised OC number and the resulting revised RPN. In the course of this exercise the original Probability of Failure Index depicted in Table 1 was expanded and modified as illustrated in Table 2.

Probability of Failure Index

Evidence about the Failure Scenario	Probability Index (Scale: 1 to 10)
Known to have occurred more than once with documented evidence in other applications with similar function.	10
Known to have occurred once with documented evidence in other applications with similar function.	8
Anecdotal evidence of previous occurrence(s) in other applications or of related failure scenarios in similar applications.	6
No history of previous occurrence(s) but potential to occur exists in the event of one or two failures.	4
No history of previous occurrence(s) but potential to occur exists in the event of more than two failures.	2

Table 1

The revised OC and RPN numbers take into account the probability of failure for vehicles manufactured in accordance with the Recommended Practice and the additional knowledge gathered during the development of the Recommended Practice.

The full FMEA with the added columns and revised RPN Numbers can be obtained from the ATA Foundation, 2200 Mill Road, Alexandria, VA 22314.

Expanded Probability of Failure Index

Evidence about the Failure Scenario	Probability Index (Scale: 1 to 10)
Known to have occurred more than once with documented evidence in other applications with similar function.	10
Reduction from Probability Index of 10 by mitigation procedures.	9
Known to have occurred once with documented evidence in other applications with similar function. Reduction from higher Probability Index by failure mode avoidance through construction constraints.	8
Reduction from Probability Index of 8 by mitigation procedures	7
Anecdotal evidence of previous occurrence(s) in other applications or of related failure scenarios in similar applications. Reduction from higher Probability Index by failure mode avoidance through construction constraints.	6
Reduction from Probability Index of 6 by mitigation procedures	5
No history of previous occurrence(s) but potential to occur exists in the event of one or two failures. Reduction from higher Probability Index by failure mode avoidance through construction constraints.	4
Reduction from Probability Index of 4 by mitigation procedures	3
No history of previous occurrence(s) but potential to occur exists in the event of more than two failures. Reduction from higher Probability Index by failure mode avoidance through construction constraints.	2
Conclusive evidence that failure mode will not occur.	1

Table 2